ARM CLIMATE RESEARCH FACILITY

Developing and Evaluating Ice Cloud Parameterizations by Combining Radar and in Situ Observations

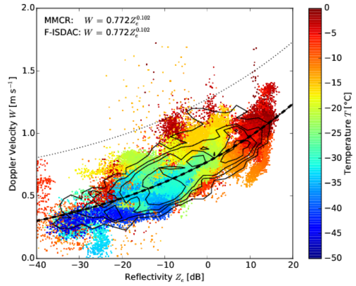
Research Highlight

One of the main challenges to measure ice clouds by remote sensing is that the transfer functions which relate the observables (e. g., radar Doppler spectrum) to cloud properties (e. g., ice water content, or IWC) are not uniquely defined. To overcome this challenge, this study has two main objectives: 1) estimate a mass-size relation m(D) from a combination of in situ and radar observations and 2) investigate the effect of describing particle area A and number concentration N as functions of size D on moments of the radar Doppler spectrum. In order to develop the set of parameters to describe m(D), A(D) and N(D), we combined observations of the Millimeter Wavelength Cloud Radar (MMCR) at the ARM site North Slope of Alaska in Barrow with in situ aircraft data acquired during the Indirect and Semi-Direct Aerosol Campaign (ISDAC).

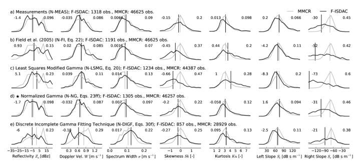
The first objective is investigated in this study, because m(D) introduces one of the greatest uncertainties when relating remote sensing observables to meteorological quantities. At the same time, m(D) is particularly difficult to measure in situ. In this study, we estimate m(D) as a function of temperature by combining radar observations with aircraft in situ measurements. We use optimal estimation and the Passive and Active Microwave TRAnsfer model (PAMTRA) radar simulator in order to find the pair of m(D) coefficients such that the functional relation between effective radar reflectivity factor Ze and Doppler velocity W (here, positive values refer to downward motion) observed by radar and (forward modeled) in situ data match. Fig. 1 shows that this leads to a high agreement of the Ze-W relation as measured by the radar (with color indicating temperature) and the forward modeled ISDAC data (contour lines). The retrieved set of coefficients of m(D) relations is similar to coefficients presented in literature and shows the transition of the dominant shape of snow particles as a function of temperature. The particles change from compact, columnar polycrystals typical for cold temperatures, to more fluffy particles, such as aggregated crystals or stellar single crystals, to heavy, rimed particles for T > #15 °C.

Knowledge of m(D) enables us to investigate the second objective, the impact of parametrizing A(D) and N(D). Similar to m(D), A(D) is commonly expressed by a power law. Gamma and exponential distributions are commonly used to describe N(D) for snow and ice. The ISDAC data set with measured profiles of A(D) and N(D) allows us to investigate the impact of applying these functions on simulated radar observations. For this, not only the standard moments Ze, W and Doppler spectrum width # are investigated, but also the use of higher moments of the Doppler spectrum, such as skewness (Sk, third moment) and kurtosis (Ku, fourth moment) together with left slope ("slow" side of the spectrum) and right slope ("fast" side of the spectrum) of the peak (Sl and Sr), is proposed as a proxy for the shape of the radar Doppler spectrum. For the following, we will call Sk, Ku, Sl and Sr higher moments even though the slopes are technically not moments. Consequently, Ze , W and # will be called lower moments. For A(D) we find that even though power law fits are well suited to describe A(D) and lead to a high agreement of lower moments, consistent results for higher moments can be only obtained if an additional, size dependent noise factor is applied to the result of the power law. We conclude that small deviations from the power law for single parts of A(D) are essential to obtain realistic Doppler spectra. For N(D), the various parametrizations are evaluated by comparing histograms of MMCR and forward modeled ISDAC data (Fig. 2). Best agreement of the distributions of both, higher and lower moments, is found for a gamma distribution, if the coefficients are estimated using a moment preserving approach. Of these, the normalized gamma distribution approach, which was modified to work with maximum dimension as size descriptor, is identified to work best for the ISDAC data set.

Both parts together result in a consistent set of equations to describe m(D), A(D) and N(D) for simulating radar observations. For this, the use of the relation between Ze



Ze vs. W as measured by MMCR with color showing temperature. The dashed line (mostly hidden by the solid line) denotes the result of the least squares fit of the radar data. The dotted line is used to remove outliers. The contour plot shows forward modeled ISDAC data for the retrieved m(D) for the full data set and the resulting least squares fit (solid line).



Normalized histograms of the radar moments (columns) of MMCR observations (gray lines) and forward-modeled ISDAC observations (black lines) for various methods to describe N(D) (rows) when forward modeling ISDAC data. For each data set, the number of cases is given. The vertical lines denote the median of the distributions, the difference between both medians is denoted in the upper left corner, and the Kolmogorov – Smirnov statistic is presented in the upper right corner of each panel.

and W as well as the use of higher moments are found to be a valuable addition. A consistent set of equations is an essential prerequisite for sensitivity studies and the development of radar retrievals exploiting radar moments. Then, the information content, which higher moments or the full radar Doppler spectrum can provide to ice cloud retrievals can be estimated using inverse retrieval methods, such as optimal estimation. In addition, the impact of using an optimized radar configuration or the addition of further observation frequencies can be investigated.

Reference(s)

Maahn M, U Löhnert, P Kollias, RC Jackson, and GM McFarquhar. 2015. "Developing and Evaluating Ice Cloud Parameterizations for Forward Modeling of Radar Moments Using In Situ Aircraft Observations." Journal of Atmospheric and Oceanic Technology, , doi:10.1175/JTECH-D-14-00112.1. ONLINE.

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Working Group(s)

Cloud Life Cycle, Cloud-Aerosol-Precipitation Interactions